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MULTI-STAGE WATER AND AMMONIA REFRIGERATION SYSTEMS IN THE LIGHT OF OZONE HOLE PROBLEM

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ABSTRACT

The present paper lays emphasis on the use of water and ammonia for air conditioning and other applications, being not a party to the ozone hole problem. In addition, the thermodynamic analyses of the 2-stage and 3-stage water refrigeration systems render their COPs higher than those of the commonly used R-11 and R-12 centrifugals for air conditioning applications. Further, they are cheapest among refrigerants and ammonia would be tolerably safe under the modified scheme. If a 2-stage ammonia refrigeration is employed in cold storage, about 9% of energy may be saved.

The vapour-absorption system operating on primary energy proves to be superior to the electrically powered vapour-compression refrigeration as the latter adds to the environmental warming over twice as compared to the former.

INTRODUCTION

In the early 1920s concerted efforts were made to find substitutes of the commonly used toxic refrigerants: ammonia, sulphur dioxide, methyl chloride, etc. *Charles Kettering and Dr. Thomas Migley Jr.* finally succeeded in inventing CFCs in 1928 as suitable refrigerants. It gave a great boost to the refrigeration industry for over three decades until the ozone hole was detected, posing the very existence of the only planet containing living being. On the other hand, the present industry is so much dependent upon the use of CFCs that its phasing out is posing serious constraint to comply with *Montreal Protocol and Helsinki Declaration.* Some industries have taken the matter rather very seriously and succeeded in finding substitutes R-123 and R-134a for R-11 and R-12, respectively. But their availability is scarce and they are very expensive (4 times at the existing level).

These substitutes with negligible ODP (Ozone Depletion Potential) seem to have a long term solution for checking ozone hole. *Hovever, the question still remains as to whether 100% guarantee may be ascertained that they may not render some other global problems in future.* Hence, the choice, even though not very pleasing, rests with the use of the proven refrigerants, water and ammonia, for several applications. They are best among all refrigerants except the large specific volume and limitation of evaporator temperature (not below 4 °C) for the former and toxicity for the latter [1,2]. Table 1 shows the comparison among the volume flow rates for various refrigerants [3,4]. *It is interesting to note that the displacement volume of ammonia is quite close to those of other common refrigerants.*

TABLE 1

Systems using various refrigerants(T_h = 40.6 °C, T_l = 1.7 °C)

Refrigerant	Volume flow rate with ton capacity(m^3/s)		
	200	300	400
R-11	1.664	2.964	3.327
R-12	0.316	0.474	0.632
R-22	0.201	0.302	0.403
R-717	0.282	0.4225	0.563

*Values calculated from [3,4].

Because of 0.05 ODP of R-22, it has not been included into the list of phasing out refrigerants prepared by UNEP (United Nations Environmental Programme). It is also being considered for low temperature applications [5].

WATER AS REFRIGERANT

There are several air conditioning applications such as various types of computers, research laboratories, workshops, stores, offices, etc., where chilled water at 6 to 11 °C is quite sufficient. Hence, in this range many air conditioning plants can be replaced by water centrifugal refrigeration.

TWO-STAGE REFRIGERATION SYSTEM

Thermodynamic Analysis Of Two-Stage Refrigeration Cycle

Figure 1 depicts a two-stage refrigeration system having a flash chamber gas inter cooler. The operating pressures are p_1 and p_2. Then, for a given TR ton of refrigeration one has:

$$\dot{m}_1 = 3.5\ TR/(h_1 - h_4) \qquad (1)$$

$$\dot{m}_3 = \dot{m}_1(h_2 - h_7)/(h_3 - h_5) \qquad (2)$$

$$P = \dot{m}_1(h_2 - h_1) + \dot{m}_3(h_4 - h_3) \qquad (3)$$

and,

$$COP = Q_c/P = 3.5\ TR/P \qquad (4)$$

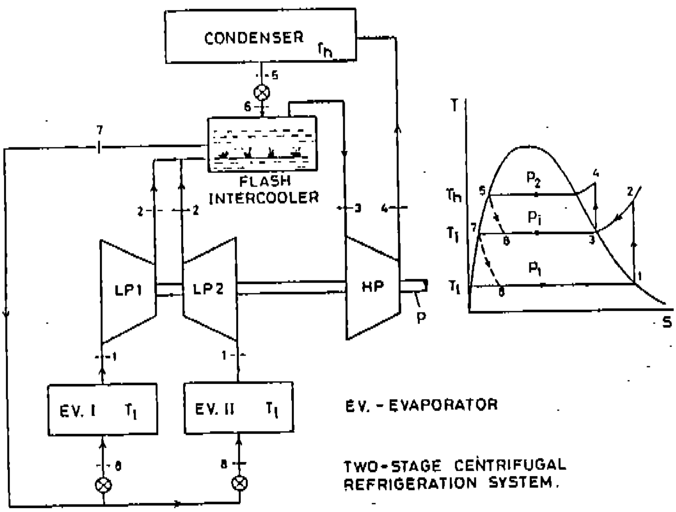

Fig. 1. Two-stage vapour-compression system with cycle.

The volume handled by LP and HP sides are found from:

$$V_1 = \dot{m}_1 v_1 \quad \text{and} \quad V_3 = \dot{m}_3 v_3 \qquad (5)$$

In the present case the intermediate pressures have been taken to be as geometric mean value, $p_i = (p_1 p_2)^{1/2}$, $0.9p_i$ and $1.15p_i$. Evaporator temperatures have been varied from 5 to 11°C, covering most of the operating conditions. Capacities have been taken to be 300 and 400 ton, being most commonly used in various applications. Properties are taken from [6]. Results have been presented in the graphical form, Fig. 2-4.

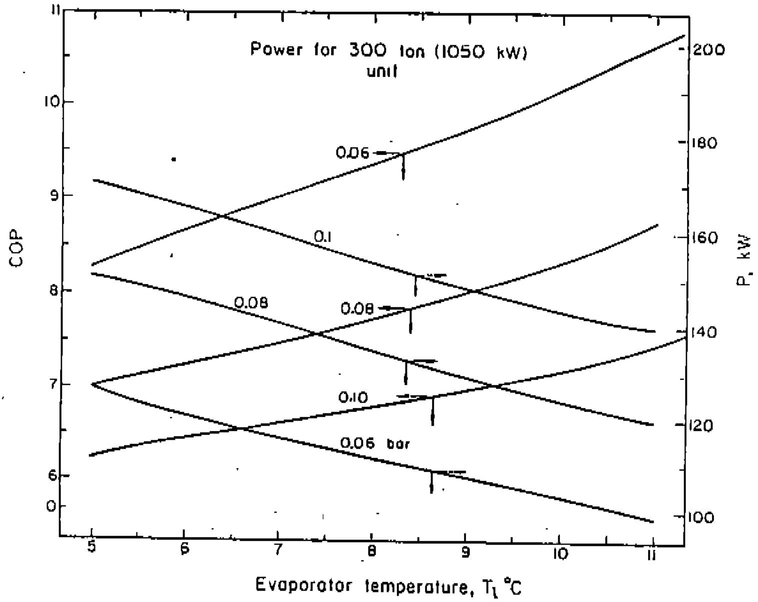

Fig. 2. COP and power for 300 ton refrigeration plant.

COPs of the present system is compared with those of R-11 and R-12 single-and multi-stage centrifugal refrigeration systems, keeping the difference in operating temperature the same, table 2, [7]. *Water refrigeration systems seem to be better than the latter.*

TABLE 2

Comparison of COPs among various centrifugal units using different refrigerants.

Refrigerant	Single-Stage	Two-stage	Three-stage	Reference
R-11	6.37	6.64	6.82	7
R-12	6.04	6.24	---	7
R-718	---	6.966*	7.082	Present
R-718	---	6.658	6.875*	work

* Condensing pressure as 0.1 bar.

Diameters for HP and LP Rotors

The volume handled by the LP compressor is enormously large. Hence, *instead of one LP compressor, two have been used, Fig.1. But, on the HP side one compressor is enough to compress vapours from* both LP compressors. Rotor diameters are calculated in order to justify the present arrangement, using thefollowing expression:

$$w = u^2 / \eta \tag{6}$$

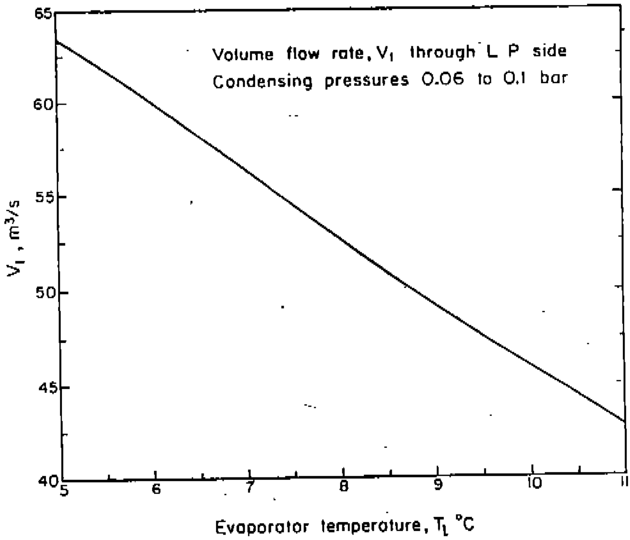

Fig. 3. Volume flow rate through LP side for 300 ton capacity plant.

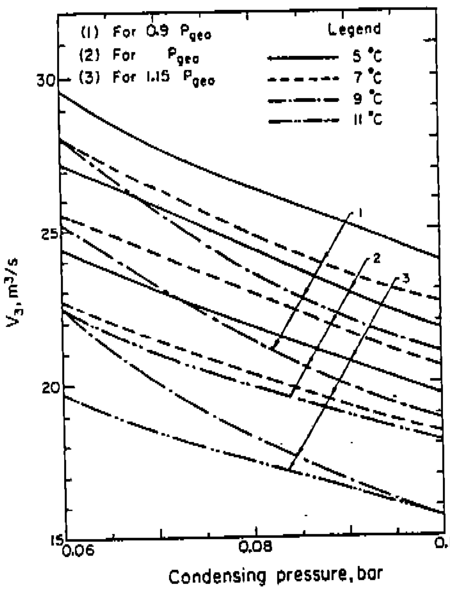

Fig. 4. Volume flow rate through HP side for 300 ton capacity plant.

Table 3 shows that water centrifugals would be bulkier than R-11 and R-12 centrifugals, requiring more investment in their manufacture. The same may be compensated by the cost free water as a refrigerant.

TABLE 3

Diameters (mm) of 300 ton (1050 kW) multi-stage water centrifugals for air conditioning application.

System	Operating pressures	LP-Stage	IP-Stage	HP-stage
Three-stage	0.0087, 0.02, 0.04, 0.08	648	629	610
Three-stage	0.01, 0.02, 0.04, 0.08	588	600	610
Two-stage	0.01, 0.028, 0.08	714	---	792

AMMONIA REFRIGERATION SYSTEM

Some Features

Ammonia is a proven chemical for centuries. Except for toxicity, it does not create any global problem. If it leaks into the environment, it forms NH_4OH. Further, fossil fuels on burning release traces of SO_2 which finally falls to the ground in the form of acid rain, i.e., H_2SO_3. This will get neutralized by NH_4OH. Hence, there is no chemical problem.

In India ammonia has been widely accepted by thousands of owners of the cold storage, ice manufacturers, etc. The response in favour of the use of ammonia is very encouraging for cold storage located away from the populated areas. In case of populated areas the system would be provided with an electronic sensor for ammonia gas. An analysis is made in [8] for venting out gas using a blower. This is a nice arrangement except it would take too much electric power to *exhaust* large volume of gas. *In the*

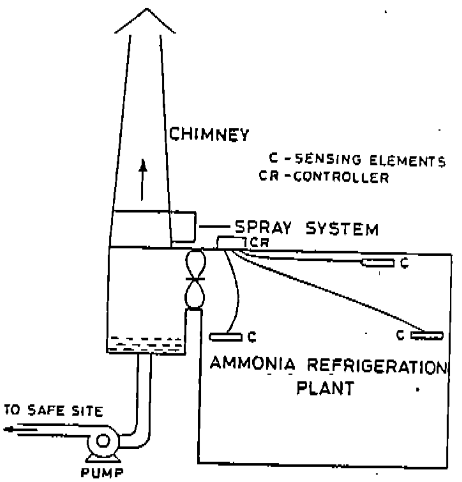

Fig. 5. Gas venting arrangement for an ammonia refrigeration plant room.

too much electric power to *exhaust* large volume of gas. *In the present case a blower would exhaust the minor leakage of ammonia from time to time through a chimney to a safe level, Fig. 5. In the event of major* leakage *or accidental breakdown, a water spray arrangement would be automatically put into operation by the electronic control device, thereby absorption of ammonia by water. Water containing ammonia will be discharged to a safe site.*

Table 4 represents COPs of single-stage and two-stage ammonia refrigeration systems. Their performance falls between R-11 and R-12. Hence, it has a very good scope for replacing them using the modified scheme. Further, there is growing need to replace the single-stage by two-stage ammonia system in order to save about 9% of energy.

Table 4

COPs of one-and two-stage ammonia refrigeration system

System	Operating conditions	COP	Remark
One-stage	$T_l = 2$ °C, $T_h = 41$ °C	5.993	
One-stage	$T_l = -6$ °C, $T_h = 40$ °C	4.791	
Two-stage	$T_l = -6$ °C, $T_h = 40$ °C $T_l^h = 15$ °C	5.235	9.26 % improvement

ENVIRONMENTAL WARMING

CFCs add to the greenhouse effects to about 7% [9]. This is quite low as compared to the greenhouse gases, CO_2, NO_2, .etc. But one can estimate the indirect addition to the global warming due to refrigeration by calculating power in terms of primary energy.

In India 1.5 ton window air conditioner, generally used in offices, takes 2.5 kW of electricity for which 12 kW of primary energy is needed [10]. It implies, therefore that every unit adds 12 kW of thermal energy to the global warming. Secondly, for the hot humid countries, the power for air conditioning of a given size room is found to be 7.84 kW as against 3.1 kW for heating the same size room in cold western countries [11,12]. Hence, in addition to emission of CFCs, the former adds to the global warming quite significantly.

Most of the vapour-absorption systems use working media with no ODP, implying thereby their great promise for uses in many refrigeration industries. *Already packaged LiBr-Water absorption units are available in the range of 385 to 1060 ton capacities. The vapour-absorption system utilizes primary energy directly. COP of such units can be of the order of unity [13], being far better than those of the compression systems. The same can be seen in table 5.*

TABLE 5

Comparison between refrigeration systems in terms of primary energy for the same capacity.

System	Refrigeration capacity, kW	Primary energy, kW	Net global warmin g, kW	ODP effec
Vapour-compression	5.25	12.0	12.0	yes
Vapour-Absorption	5.25	5.25	5.25	Nil

CONCLUSIONS

1. **Water and ammonia refrigeration systems with the modified scheme have tremendous scope for a number of air conditioning applications, especially due to ozone hole problem.**

2. For the same operating temperature difference, the 2-stage and 3-stage water refrigeration systems render higher COPs than those of R-11 and R-12 centrifugals for air conditioning.

3. Ammonia may be used for large units with the modified scheme. Its COPs fall between R-11 and R-12 systems. Also water and ammonia are cheapest among the commonly used refrigerants. Hence, initial increased investment due to bulkier dimension of water refrigeration may be compensated to a significant extent.

4. The vapour-absorption system operating on the primary energy has superiority over electrically driven vapour-compression systems as the latter add more to the environmental warming.

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SYMBOLS

D - Diameter (mm)
$\dot{m}$ - Mass flow rate (kg/s)
N - RPM of compressor (taken as 11,000)
p_i -Intermediate pressure (bar)
T_h -Condensing temperature (°C)
T_l -Evaporator temperature (°C)
TR -Tonnage of refrigeration system(= 3.5 kW/ton)
v - specific volume of refrigerant (m^3/kg)
η - compression efficiency (taken to be 0.85)
h - Enthalpy (kJ/kg)
p_1 - Evaporator pressure (bar)
p_2 - Condensing pressure (bar)
T_i - Intermediate temperature(°C)
u - Tip speed of rotor (m/s)
w - work of compression (kJ/kg)